Snow-vegetation interactions at the individual tree scale with terrestrial laser scanning, Grand Mesa, Colorado

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SNOWEX

Objective

In this study we assess the relative influence of vegetation metrics at the individual tree scale along with topographic attributes on snow depths for six sites across Grand Mesa, CO. The impact of topography on snow depth distributions is investigated within canopy openings and the sub-canopy. We also examine how canopy affects snow depths at different distances from the canopy edge. The snow-off and snow-on datasets are collected by terrestrial laser scanning (TLS) during September 2016 and February 2017, respectively.

Data and Methods

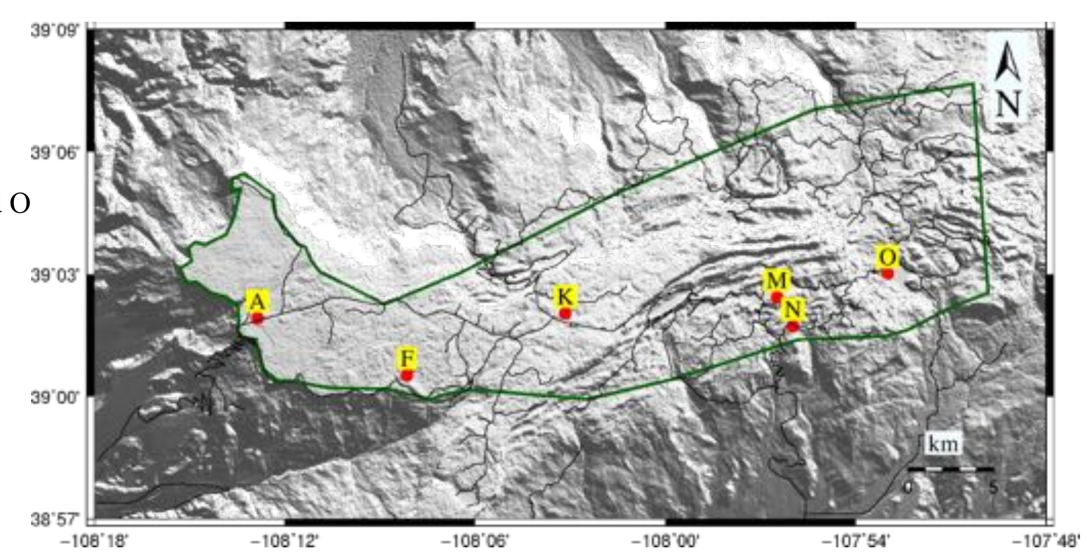

Figure 1. TLS sites A, F, K, N, N, and O collected during SnowEx Grand Mesa, 2016-2017, and used in this study.

Table 1. Summary of TLS site properties.

Sites	Area of analysis (m)	Wind direction	Vegetation type	Slope	Aspect	% tree cover	Range of tree height	Mean tree height	Std tree height
A	29128	West to East	Mostly Shrubs	0°-10°	W-NW-N , N-NE-E	9%	2 - 27 m	16.6 m	5.77
F	37838	…	Shrubs and Trees	0°-10°	SW-W-NW	24%	2 - 29.2 m	21.4 m	6.38
K	31497	…	Mostly Trees	0°-8°	W-NW-N , N-NE-E	38%	1.7 - 30 m	18.7 m	6.45
M	21994	SE to NW	Tall shrubs	0°-16°	NE-E-SE , SE-S-SW	45%	5.7 - 33.7 m	21.6 m	7.45
N	10187	…	Mostly Trees	0°-10°	NW-N, N-NE-E	52%	1.7 - 28.3 m	10.5 m	2.62
O	24302	…	Tall shrubs	0°-12°	NE-E-SE, SE-S-SW	14%	5 - 33.4 m	16.4 m	7.65

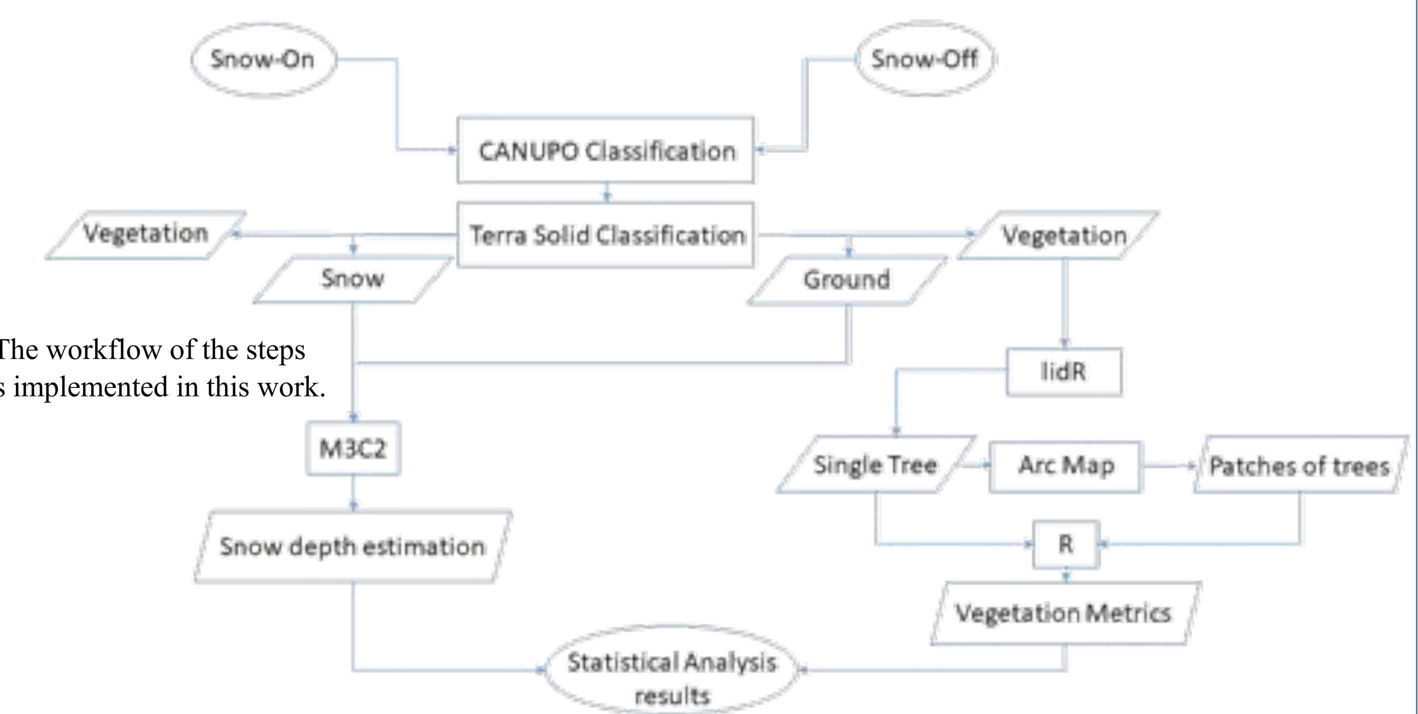

Figure 2. The workflow of the steps and methods implemented in this work.

Snow – vegetation classification

The CANUPO algorithm is used for separating ground (snow) from trees in the point clouds. The process includes:

1. **Training**, During training, the algorithm defines features related to each class (ground/snow, trees) at different scales. The main idea is that each class is seen at different dimensions per each scale and the combination of scales allows to separate the classes. For example, at cm-scales, vegetation branches are 1D and the leaves and snow are 2D. As we increase the scale to 1m, the trees are 3D and snow remains 2D. The combination of information from different scales helps the algorithm detect snow and trees at multiple scales. For defining which feature is 1D, 2D or 3D, PCA is used on points within a sphere with a diameter equal to the scale. The eigenvalues from the PCA define how 1D, 2D or 3D the cloud appears at that specific scale. The algorithm finds different dimensions of neighbor point clouds at different scales for user defined classes and then uses those in the classification of unclassified points.
2. **Classification**, in which CANUPO defines the best combination of scales to properly separate different classes. It provides visual inspection for the user to improve the classification.

Snow depth estimation

The M3C2 algorithm is used to estimate snow depth from the point clouds.

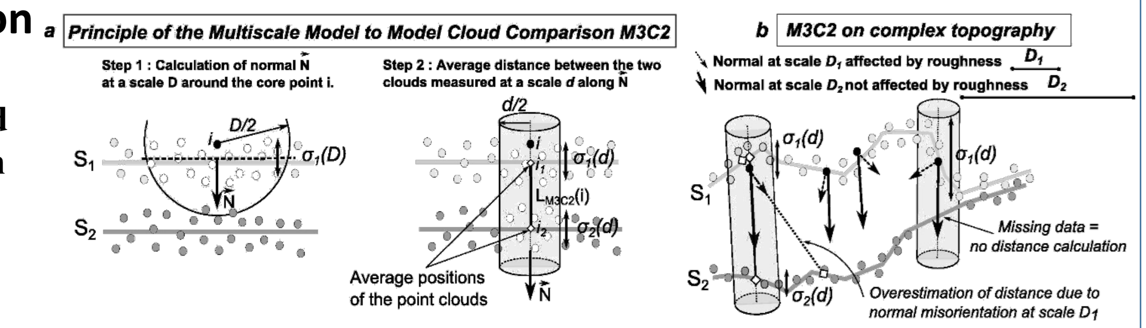

Figure 3. The M3C2 algorithm used to estimate snow depth. Lague, D., Brodu, N., & Leroux, J. (2013). [2]

Individual tree segmentation

The lidR package in R is used to separate individual trees in the point clouds.

- Normalize the vegetation height using a 0.5m DEM from snow-off point clouds
- Find the top of the trees using a range of window sizes and tree minimum height
- Rasterize the normalized (resolution = 0.5m) and apply mcwatershed for individual tree segmentation

Table 2. List of vegetation and topographic metrics used in the study.

Maximum height (**Zmax**)	Mean height (**Zmean**)	Minimum height (**Zmin**)	Height std (**Zstd**)
Height variance (**Zvar**)	Height range (**Zhgt_rng**)	Skewness (**Zskew**)	Kurtosis (**Zkurt**)
Crown volume (**crwnvlm**)	Crown surface (**crwnsrf**)	Median Absolute Deviation (**MAD**) from Median Height	Mean Absolute Deviation (**AAD**) from Mean Height
Number of tree points per each polygon	Canopy relief ratio (**CRR**)	Entropy of height distribution (**Zentropy**)	Hull surface area (**cnvhll_area**)
Percentage of returns above mean height (**pzbvzmn**)	Percentage of returns above 1m (**pzabov1**)	Percentile (quantile) of height distribution (**zq***)	Cumulative percentage of return in the x^{th} layer (**zpcum***)
Number of Lidar Vegetation Returns (**nV**)	Number of Lidar Ground Returns (**nG**)	Height Coefficient of Variation (**Zcv**)	Foliage Height Diversity (**FHD**)-All points
Aspect	Slope	Distance from the canopy edge	Surface roughness

Results

Classification and segmentation

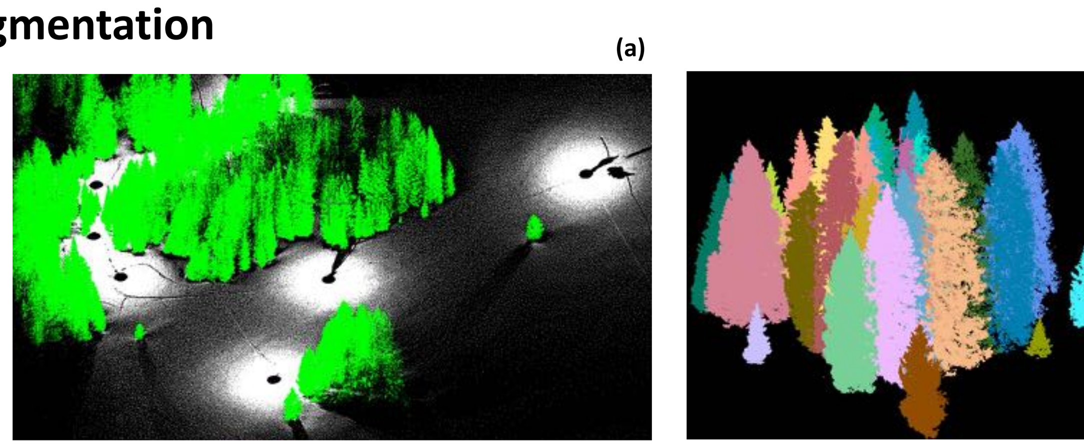

Figure 4a,b. Classification and segmentation results. (a) snow - vegetation are initially classified using the CANUPO method and cleaned in Terra Solid software. (b) example of individual tree segmentation results using lidR[3] package in R.

Snow depth estimation

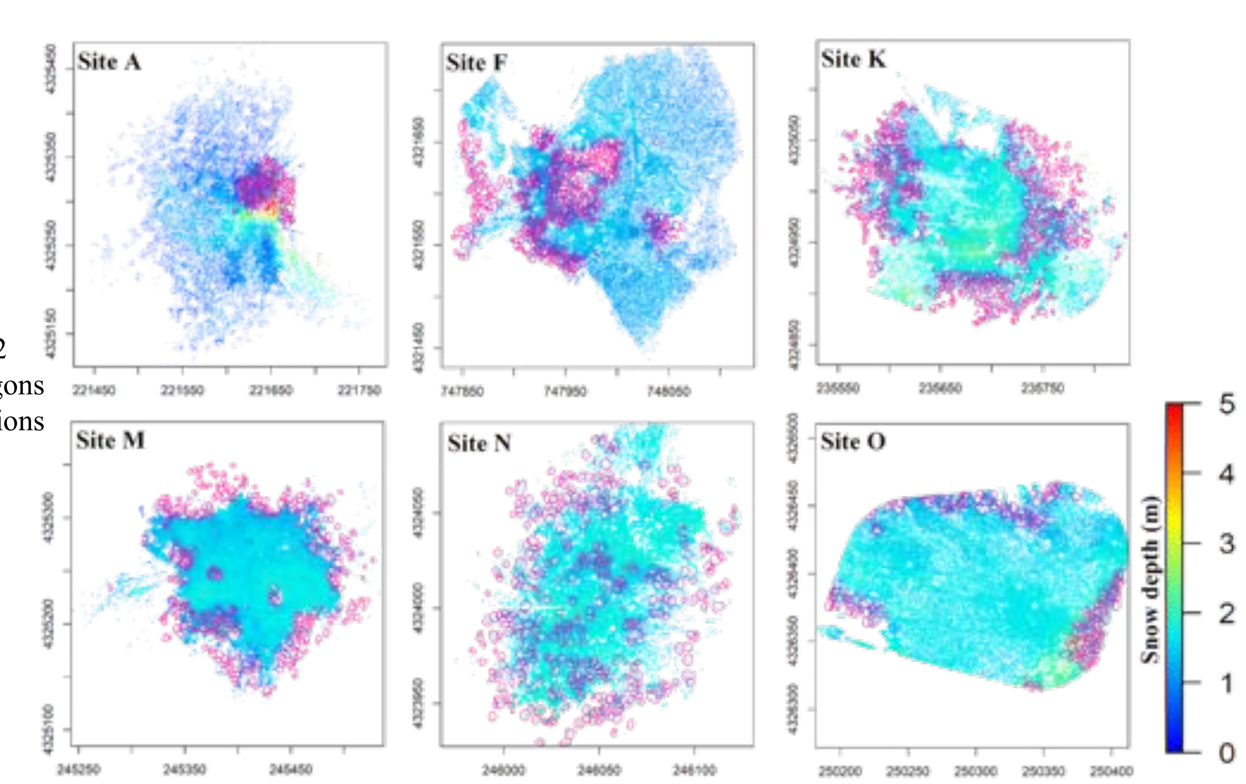

Figure 5. Snow depth estimated using the M3C2 method. The pink polygons are individual tree locations at each site.

Table 3. Snow depths in the open and in the canopy.

Sites	Open mean snow depth	Canopy mean snow depth	Open to canopy % difference
A	0.95 m	0.96 m	1%
F	1.14 m	0.87 m	23%
K	1.66 m	1.27 m	23%
M	1.44 m	1.16 m	19%
N	1.62 m	1.4 m	14%
O	1.58 m	1.33 m	16%

Snow depth and canopy edge relationships

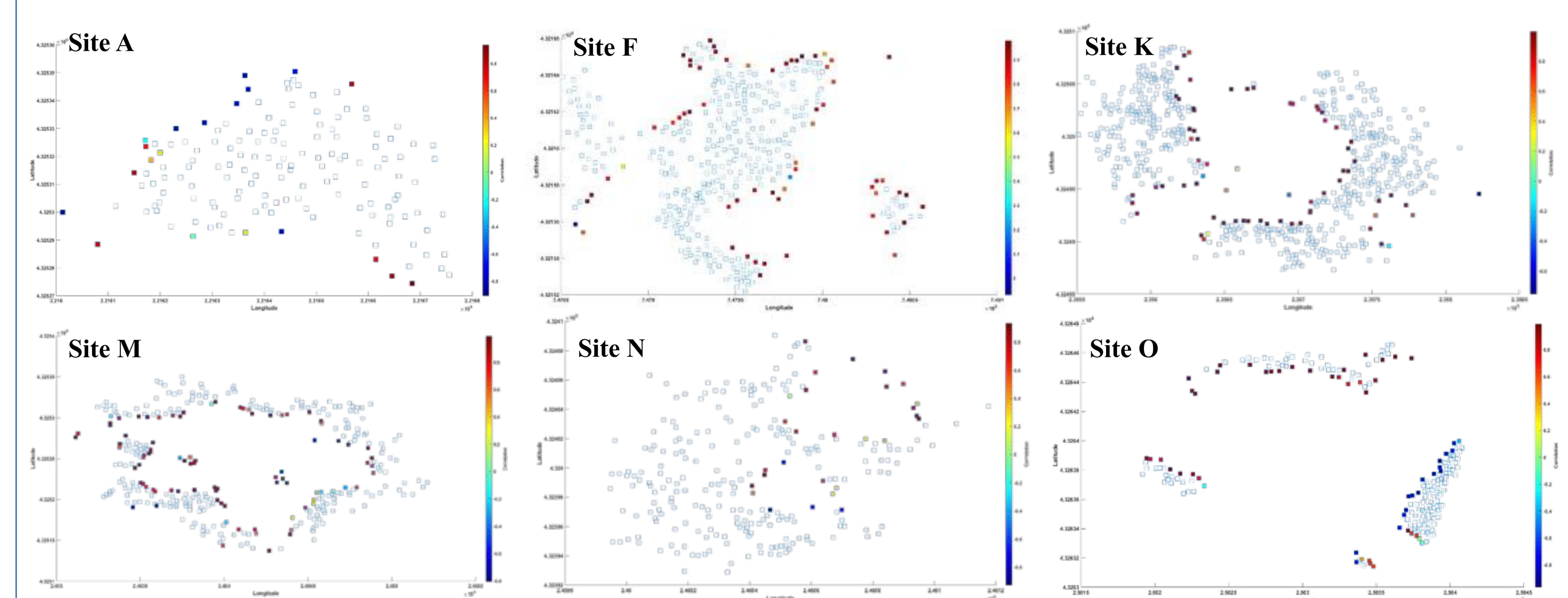

Figure 6. The correlation between snow depth and distance from the canopy edge for individual trees at all sites. Red colors are correlations near 1 which indicates snow depth increases from the canopy edge. Blue colors show negative correlation indicating snow depth decreases from canopy edge.

Aspect, slope, vegetation metrics and snow depth correlation

Table 4. The correlation between snow depth, slope, aspect and vegetation metrics for all sites. Stars indicate significance levels of 0.05. The correlation values and significant levels indicate slope and aspect significantly impact snow under the canopy at site O, but they have no effect under canopy at the other sites. In open areas, although most of the correlations are not high, the correlation test indicates those correlations are not zero. The last two columns show the first two highest correlations between vegetation metrics and snow depth. FHD has the highest correlation in most sites. For example at site F, snow depth is negatively correlated with percent of vegetation point clouds above 3m (pzabove3) and Foliage Height Diversity (FHD). In other words, trees with more canopy layers evenly distributed (FHD) or above 3 m (trees with more foliage near the top of the canopy) intercept snow and reduce snow depths below the trees.

Sites	Correlation with slope (open area)	Correlation with aspect (open area)	Correlation with slope (sub-canopy)	Correlation with aspect (sub-canopy)	Highest correlation with veg metric	2^{nd} highest correlation with veg metric
A	0.41 ***	-0.02 ***	0.12	0.25	pzabove1 (-0.68) ***	FHD (-0.47) ***
F	0.11 ***	0.02 ***	-0.059	0.095	FHD (-0.50) ***	pzabove3 (-0.48) ***
K	-0.29 ***	-0.03 ***	0.19	0.21	FHD (-0.46) ***	Zmax (-0.43) ***
M	-0.15 ***	-0.07 ***	-0.12	-0.2	zq90 (-0.16) **	pzabove4 (-0.13) *
N	0.07 ***	-0.05 ***	-0.35	0.34	FHD (-0.35) ***	pzabove3 (-0.35) ***
O	0.09 ***	0.21 ***	0.80 ***	0.49 *	FHD (-0.75) ***	zq95 (-0.75) ***

We found higher snow depths in the open than in the canopy (Table 3), with the exception of site A which is dominated by shrubs and had the lowest tree cover (Fig 5, Table 1). Although vertical canopy metrics (e.g. FHD) were the main factors in snow depth distribution at the sub-canopy level at all sites, they were outweighed by slope and aspect at site O which is characterized by an open basin (Fig 5, Table 4). Snow depths at 1-10m buffers (results not shown) from the canopy edge show that snow depth in canopy openings is highly correlated with the distance from the canopy and most correlations were positive (Fig 6).

Discussion

The density and distribution of the canopy across the sites relative to slope and aspect are important to consider. For example, sites O has a significant portion of the study area open, with trees surrounding the open area. Site A is mostly open with a small portion of trees in the northeast where snow is the deepest. At these sites, slope and aspect were more correlated to snow depths than in other sites where trees were distributed across the sites. While positive correlations between distance from edge of trees and snow depths was most common, we also found individual trees or small patches of trees with negative correlation between snow depth and distance from the edge. This indicates that the size of the patch (of trees) makes a difference. In addition, we need to incorporate dominant wind direction and speed and shadow effects (due to slope) into our study to further understand the snow depth distributions at each site.

Citations

[1] Brodu, N., Lague, D. 3D terrestrial LIDAR data classification of complex natural scenes using a multi-scale dimensionality criterion: Applications in geomorphology, ISPRS Journal of Photogrammetry and Remote Sensing, ISSN: 0924-2716, Vol: 68, Issue: 1, Page: 121-134
[2] Lague, D., Brodu, N., & Leroux, J. (2013). Accurate 3D comparison of complex topography with terrestrial laser scanner: Application to the Rangitikei canyon (N-Z). *ISPRS Journal of Photogrammetry and Remote Sensing, 82*, 10-26.
[3] https://github.com/Jean-Romain/lidR/wiki/stdmetrics

*This work was supported by NASA THP17 80NSSC18K0955. Thanks to Ann Marie Raymondi and Chelsea Merriman for assistance in collecting TLS data.